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Stated choice model of transport modes including solar bike

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Abstract: In the Netherlands, e-bike ownership and use has rapidly increased over the last decade. A new type of e-bike, the solar bike, has recently been developed. The solar bike is an electric bike with solar panels in the front wheel that charges through sunlight. The aim of this study is to gain more insight in the factors affecting people's choice between different transport modes, including car, public transport, regular bike, e-bike and solar bike. Based on a stated choice experiment among 308 respondents, a mixed logit error components model for transport mode choice was estimated. The results show that the solar bike is preferred for medium-length trips during daylight and in good weather. Land-use attributes such as good bike lanes, secured bike parking, congested roads and paid parking also have a positive effect on choosing a solar bike over a car. In addition, a latent class model was estimated to segment respondents according to their base preferences for transport modes. Three segments were identified: a segment with a preference for the solar bike, a segment of car lovers and a segment with a preference for public transport and a regular bike. Chi-square and ANOVA tests show that solar bike affinity is related to being female, older, Dutch, and having a positive attitude toward e-bike, solar bike, innovation and the environment.

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1 Introduction

The popularity of pedal assisted e-bikes (also called pedelecs) is growing rapidly. China is leading with regard to e-bike sales (e.g., Cherry & Cervero, 2007), followed in Europe by Switzerland, the Netherlands, Austria and Germany (Haustein & Møller, 2016). In 2014, one in every five bikes that were sold in the Netherlands was an e-bike (Bovag-RAI, 2015). E-bikes in the Netherlands are

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typically regulated at 250W maximum power output and a maximum speed up to 25 km/hour, and are allowed on dedicated bicycle paths. A new type of e-bike was recently developed: the solar bike. This is an e-bike that charges through solar panels in the front wheel. The solar bike thus has the advantage of a larger range and independency of charging compared to a regular e-bike, and it has the advantage of pedal support over a regular bike. Figure 1 shows the solar bike that was developed by Abby in Eindhoven.

Figure 1: Solar bike

Compared to motorized travel, cycling involves several benefits. Cycling is cheap, both for individuals (cheap to purchase a bike) as for cities (inexpensive infrastructure). It is environmentally friendly, produces hardly any noise and it is good for public health (Heinen, Wee, & Maat, 2010). Policy makers therefore aim to increase levels of cycling.

The Netherlands is known for its bicycle culture. In the Netherlands around a quarter of all trips are made by bike. For trips up to 7.5 kilometers the bike is used for one third of all trips. However, the share of bikes decreases rapidly when distance increases. Only 15% of all trips between 7.5 and 15 kilometers are made by bike (Ministry of Transport, Public Works and Water Management & Fietsberaad, 2009). E-bikes and solar bikes may be promising in this respect. The pedal support of e-bikes allows to cycle longer trips compared to a regular bike. For the average commute distance of 17.5 kilometers it may be feasible to use an electric bike or solar bike.

Because of their pedal support, e-bikes and solar bikes may substitute trips otherwise made by car. However, according to Fyhri and Fearnley (2015) the potential of e-bikes to replace motorized travel still remains to be proven. There are concerns that e-bikes will only replace cycling on regular bikes instead of motorized travel. Kroesen (2017) indeed found that e-bike ownership strongly reduces the use of a regular bike, but it also reduces car and public transport use. According to the study of Lee, Molin, Maat, and Sierzchula (2015) 41% of the trips made by e-bike would have been made by regular bike and 40% would have been made by car if an e-bike were not available.

Common reasons to purchase an e-bike are to ride with less effort or without getting exhausted (Johnson & Rose, 2015; Haustein & Møller, 2016), to ride longer distances over hills (Dill & Rose, 2012; Haustein & Møller, 2016), or to keep riding with a health condition (Johnson & Rose, 2015;

Jones, Harms, & Heinen, 2016). However, to replace car trips is an important reason as well (Johnson & Rose, 2015; Haustein & Møller, 2016). Jones et al. (2016) found that e-biking not only replaced regular cycling but also car travel. The first target groups for e-bikes were women, older adults and people with a physical condition (Dill & Rose, 2012). However, this has rapidly expanded to other groups as well (Haustein & Møller, 2016).

The aim of this study is to gain more insight in the land use and trip characteristics affecting people's choice between different transport modes, including car, public transport, regular bike, e-bike and solar bike. It will provide interesting insights for product developers regarding the stated use of the solar bike. Moreover, the results of this study will be of use for land-use planners and policy makers aiming to stimulate bicycle use.

For this study an online survey is used, including a stated choice experiment. With this experiment the effects of several situational conditions on transport mode choice are measured. The data will be analyzed using a mixed logit error components model. In addition, a latent class model is used to segment respondents according to their base transport mode preferences.

The paper is organized as follows. In the next Section the literature on factors influencing e-bike use will be reviewed. In Section 3 the survey and data collection will be described. Section 4 presents the modeling results. The last Section contains the conclusions and recommendations for policy and practice.

2 Literature review

This section reviews the literature on bike and e-bike use as an outcome of transport mode choice. While the literature on transport mode choice and factors influencing cycling is vast, only a relatively limited number of studies have focused on e-bike use so far. Besides an earlier paper (van den Berg, Vinken, Geurs, & Arentze, 2017) in which we examined the factors influencing people's intentions to purchase a solar bike, no studies so far have investigated mode choice behavior including the solar bike as a choice option. Our literature review will therefore mainly focus on the land use and trip characteristics that have been found to affect e-bike and regular bike use, without aiming to be extensive.

The literature suggests that levels of cycling are affected by characteristics of the present infrastructure and transport facilities regarding cycling as well as for other transport modes. For instance, good quality of cycling infrastructure in the area (both perceived and objective) has been found to be related to higher levels of cycling (e.g. Hoehner, Ramierz, Elliott, Handy, & Brownson, 2005; Parkin, Wardman, & Page, 2008; Buehler & Pucher, 2011; Santos, Maoh, Potoglou, & Von Brunn, 2013; Piatowski & Marshall, 2015; Braun et al., 2016). In addition, free car parking at work has been found to stimulate car use, whereas a parking fee reduces car use at the expense of public transport and bike (Hess, 2001; Rietveld & Daniel, 2004; Hamre & Buehler, 2014). In our previous study on solar bikes (van den Berg et al., 2017) we also found that people are more willing to purchase a solar bike when quality of bike lanes is better, when car parking is more expensive and when the quality of public transport is lower. Car and transit congestion may also increase people's preference for alternative modes.

Besides characteristics of the transport system, transport mode choice is also affected by specific trip characteristics. For instance, Molin and Timmermans (2010) found significant effects of trip purpose, weather, distance, time of day, route knowledge, luggage and travel party on train egress mode choice. They found that people are more likely to choose the bike when it is dry and light, when people know their route and when they travel without heavy luggage. Longer trips reduced the share of bikes, and more costly modes were more likely to be chosen for trips to work (Molin & Timmermans, 2010).

Finally, cycling is related to personal socio-demographic characteristics and perceptions. For instance, females tend to cycle less than males (e.g., Heinen et al., 2010; MacArthur, Dill, & Person, 2014; Piatkowski & Marshall, 2015; Braun et al., 2016), because of safety concerns. Families with younger children have also been found to cycle less (Ryley, 2006). Cycling is also lower among older people (Braun et al., 2016). However, because of the pedal support e-bikes provide opportunities to remain cycling without exhaustion. E-bikes are therefore popular among older adults and people with a physical condition that makes riding a regular bike difficult (MacArthur et al., 2014; Wolf & Seebauer, 2014). Research has shown that people who own a car are more likely to drive and less likely to cycle (e.g., Rietveld et al., 2004; Parkin et al, 2008; Piatkowski & Marshall, 2015). Findings on the relationship between education and income and cycling are not consistent (Piatkowski & Marshall, 2015). Our study on solar bike purchase intention showed that higher educated, unemployed or retired people with a commute distance between 7 and 12 kilometers are most likely to buy a solar bike (Van den Berg et al., 2017).

With regard to attitudes and perceptions, De Geus, Bourdeaudhuij, James, and Meeusen (2008) also found that people who are more aware of the environment cycle more. Wolf and Seebauer (2014) found that e-bike users are more environmentally friendly and more interested in innovative technologies. Our previous study showed that people who are more positive toward innovation, are more likely to purchase a solar bike (Van den Berg et al., 2017).

This short review of the literature has shown that transport mode choice, including e-bike use is affected by characteristics of the infrastructure, trip characteristics, personal attributes and perceptions. These factors are therefore used in our study to predict the effects on mode share of solar bikes.

3 Survey and data collection

To collect data for this study, an online questionnaire was developed. The questionnaire consisted of three parts. The first part asked questions on socio-demographics of the respondents, such as age, gender, household composition, occupation, income, distance to work or school and vehicle ownership.

The second part of the questionnaire contained a stated choice experiment. In the experiment, respondents were presented 9 choice tasks in which trip attributes varied. The choice scenarios were presented to the respondents in a random order to avoid possible order effects. Figure 2 shows the explanation of the choice task, and figure 3 shows an example of a choice task in the survey.

The attributes of trips were varied using a fractional factorial orthogonal design consisting of 27 profiles. For each choice task the respondents were asked to choose their preferred transport mode for this trip. They could choose from regular bike, e-bike, solar bike, public transport or car. Table 1 shows the trip attributes and their levels that were varied in the choice tasks. In order not to include too many attributes in the choice experiment, only trips characteristics are included. Characteristics of the choice alternatives, such as travel time and costs are not included in the choice experiment. Respondents most likely have a perception of these choice alternative characteristics based on previous experience with these alternatives, which they take into account when making their choices.

Table 1: Trip attributes in stated choice experiment

Attributes	**Levels**
Trip distance	[1] 6 km
	[2] 14 km
	[3] 22 km
Trip purpose	[1] Commuting
	[2] Recreation
Weather	[1] Windy & rainy
	[2] Little wind & rain
	[3] Little wind & dry
Daylight	[1] Daylight
	[2] Dark
Quality bike lanes	[1] Bad
	[2] Moderate
	[3] Good
Bike parking	[1] Free parking on own risk
	[2] Secured parking for free
	[3] Secured parking with additional fee (€1 per day)
Public transport quality	[1] Bad
	[2] Moderate
	[3] Good
Crowdedness public transport	[1] Crowded
	[2] Moderate
	[3] Calm
Crowdedness car	[1] Crowded
	[2] Moderate
	[3] Calm
Car parking	[1] Free parking
	[2] Parking for € 3.75
	[3] Parking for € 7.50

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Part 3 – Transportation mode choice - Explanation

In this part of the questionnaire we will present you nine different choice situations. In the presented choice situations you have to make a trip for a particular purpose and there are several transport modes between which you can choose, where you should choose which transport mode you prefer in that particular situation. You may assume that you have a Solar bike which you could use for the trip. However, there are also other options that you could choose. In these choice situations the following aspects can differ:

1. Trip distance(also used in part 2): Options - *6, 16 and 22 km*
This is your travel distance of a one way trip, for example your distance to work.

2. Purpose of trip: Options - *Commuting and Recreation*

3. Weather: Options - *Windy & rainy, Little wind & rain and Little wind & dry*
The weather conditions for the biggest part of the given situation.

4. Time of day: Options - *Daylight and Dark*

5. Type and quality of bike lanes (also used in part 2): Options - *Good, Moderate and Bad*
The overall type and quality of bike lanes in the given situation.

Good (separate bike path) , Moderate (semi-separate bike path) and Bad (no bike path)

6. Public transport quality (also used in part 2): Options - *Good, Moderate and Bad*
The quality of the public transport, expressed in frequency and amount of stops.
Good – High frequency and few stops
Moderate – Moderate frequency and stops
Bad – Low frequency and many stops

7. Crowdedness public transport: Options - *Crowded, Semi-crowded and Calm*
The crowdedness of the public transport, determined by the amount of seating place available. Whereas crowded means a small chance of seating place available, semi-crowded some seating place available and calm plenty of seating place available.

8. Bike parking (also used in part 2): Options - *Free bike parking on own risk, Secured bike parking for free, and Secured bike parking with additional fee (€1 per day)*

9. Car parking(also used in part 2): Options - *Free car parking, Car parking for € 3,75 , and Car parking for € 7,50*

10. Car traffic jams: Options - *Calm, Moderate and Congested*
The condition of car traffic jams with its corresponding time delay. Whereas calm indicates no car traffic jams with no delay, moderate car traffic jams with ± 10 min delay in total, and congested car traffic jams with ± 20 min delay in total.

When evaluating the choice situations you should try to imagine the situation as your actual situation, and choose which transport mode you would prefer in that particular situation. An example question is given here:

Figure 2: Explanation of choice task

Your specific trip, considering the following specifications *1	
Trip distance	16 km
Purpose of trip	Commuting
Weather	Little wind and dry
Time of day	Daylight
Type and quality bike lanes	Good
Public transport quality	Moderate
Crowdedness public transport	Calm
Bike parking	Secured bike parking for free
Car parking	Car parking for € 3,75
Car traffic jams	Congested (± 20 min delay)

*1 Explanation: Your specific trip is a one-way trip of *16 km* and the purpose of your trip is *commuting*. The weather conditions are *little wind and dry*, with *daylight* as time of day. The type and quality of bike lanes are *good*, whereas the public transport quality is *moderate*. Also the *crowdedness* of the public transport is *calm*. The bike parking is *secured and free of costs*, the *car parking is for € 3,75*. Additionally, there are many car traffic jams and the car roads are *congested (± 20 min delay)*

	Solar bike	E-bike	Regular Bike	Bus/Tram/Metro	Car	Motor
Which transportation mode would you choose? *2	☐	○	○	○	○	○

*2 Explanation: Considering the above situation, which transport mode would you choose? A *Solar Bike, E-bike, Regular bike, Bus/ Tram/ Metro, Car or Motor*? All transport mode options are in this case available for you to choose, even if you don't own one of the above transport mode options

Figure 3: Example of choice task

The third part of the questionnaire contained questions to measure people's perception of or attitudes toward e-bikes and solar bikes, innovation and being environmentally friendly. These attitudes were measured using statements which could be answered on a five-point scale ranging from strongly disagree (1) to strongly agree (5).

E-bike perception was measured using the following seven statements:

1. An e-bike looks highly sensitive and vulnerable object
2. The image of an e-bike equals elderly
3. The image of an e-bike equals non-sportive people
4. An e-bike is a trendy and innovative product
5. The fact that e-bikes are often stolen, makes buying an e-bike less attractive
6. An e-bike contributes to a healthier lifestyle and daily exercise
7. An e-bike contributes to a more sustainable and greener world

To measure the attitude toward solar bikes, the same statements were used replacing e-bike with solar bike. The first statement was replaced with the following:

1. A solar bike would give me a high amount of flexibility and freedom of movement, because charging is unnecessary

The perception of being environmentally friendly was measured using six statements:

1. I am concerned about global warming and tend to work for a better and greener world
2. I would pay more money for reducing CO_2 emissions in new products
3. It doesn't make any point to not use a car for a better and greener world, others will remain driving their car.
4. For a better and greener world, I try to use the car less often

5. The environment benefits if people sometimes don't use their cars.
6. It is pointless to worry about a better and greener world; you can't solve it on your own.

The attitude toward innovation was measured using a single statement, namely: "I am very interested in new and innovative products and like to purchase and test them as soon as possible".

The data collection for this project started in May 2015. The link to the online survey was emailed to employees of the department of the Built Environment at Eindhoven University of Technology and the Faculty of Engineering Technology at the University of Twente. It was also posted on social media such as LinkedIn, Twitter and Facebook. Leaflets with the link to the questionnaire were distributed at the High Tech Campus in Eindhoven and the Dream & Dare Festival at the campus of Eindhoven University of Technology.

A total of 308 respondents took part in the survey. The characteristics of the sample are shown in Table 2. The percentages of the population were retrieved from Statistics Netherlands (2016). The results show that a relatively large share (43%) of the respondents is between 18 and 34 years of age; 27% is between 35 and 49 and 31% is 50 or over. Men are slightly overrepresented in the sample with 58%. The majority of the respondents (87%) are Dutch. Single person households make up almost a quarter of the sample; 40% live with a partner and 37% have a family with children. Almost half of the respondents have a commute distance between 0 and 6 kilometers. As a result of the recruitment at the universities, highly educated people make up a large share of the sample (89%). The same goes for full time working people (58%). Regarding vehicle ownership three quarters of the sample own one or more cars, 11% owns an e-bike, and a little more than half of the sample owns a public transport card with discount or free travel subscription.

Table 2: Sample characteristics

Variable	Levels	N	%	% NL
Age	18 - 34	132	43%	26%
	35 - 49	82	27%	25%
	50 +	94	31%	49%
Gender	Male	178	58%	50%
	Female	130	42%	50%
Nationality	Dutch	269	87%	78%
	Other	39	13%	22%
Household composition	Single	71	23%	37%
	Couple (without children)	122	40%	28%
	Family with children	115	37%	65%
Commute distance	0 - 6 km	138	45%	
	7 - 12 km	49	16%	
	13 - 24 km	39	13%	
	25+ km	82	27%	
Personal gross income per month	€ 0 - € 1900	86	28%	
	€ 1901 - € 2700	63	21%	
	€ 2701 - € 3500	64	21%	
	> € 3500	95	31%	
Education	Secondary education	33	11%	
	Higher education (BSc or higher)	275	89%	
Main occupation	Unemployed/retired	20	6%	
	Student	48	16%	
	Working part-time (<32 hours per week)	61	20%	
	Working full-time (> 32 hours per week)	179	58%	
Number of cars in household	None	74	24%	
	One	142	46%	
	Two or more	92	30%	
Ownership e-bike	Yes	34	11%	
	No	274	89%	
Public transport card with discount/free travel	Yes	166	54%	
	No	142	46%	

4 Modeling results

In this section, the modeling results will be presented. Two models are estimated, based on the data of the transport mode choice experiment. The first model aims to predict transport mode choice as a function of the different trip attributes. Because each respondent had several choice situations and preference heterogeneity between respondents can be expected, a mixed logit error components model is estimated. The second model is a latent class multinomial logit (MNL) model, an extended version of traditional MNL models to explain preference heterogeneity between respondents, without having to make strong distributional assumptions about individual heterogeneity (e.g., Greene & Hensher, 2003). This model groups the respondents into segments with separate parameters for the transport mode constants. Segment membership is then explained using bivariate analyses: crosstabs with Chi-square tests and ANOVA tests. Both models account for the panel nature of the data (the same respondent making several choices).

In the choice experiment, a total of 2711 choices were made by 308 respondents. Table 3 shows the frequencies of the chosen transport modes. As can be seen, car and regular bike were each chosen in 30% of the choice tasks. The solar bike was chosen in 16% of the choice tasks; public transport accounts for 13% and e-bike for 11% of the choices.

Table 3: Frequency transport mode choice

Mode choice	Frequency	Percentage
Solar bike	422	15.6
E-bike	291	10.7
Regular bike	825	30.4
Public Transport	348	12.8
Car	825	30.4
Total	2711	100

4.1 Results mixed logit error components model

Table 4 shows the modeling results of the mixed logit error components model. It shows the estimated parameters for solar bike, e-bike, regular bike and public transport. Car serves as the reference category. In the model, the alternative specific constants were introduced as random parameters. Moreover, the model accounts for correlation in utility over alternatives. One may assume that the error terms of the three bicycle alternatives are correlated, or at least that the error terms of e-bike and solar bike are correlated. The error terms of both motorized modes may also be correlated. Therefore, error components were specified for car and public transport (Sigma 1); the nest containing regular bike, e-bike and solar bike (Sigma 2); and the nest containing e-bike and solar bike (Sigma 3). The model accounts for correlations across the choices of the same individual.

The attribute levels presented in Table 1 are the explanatory variables in the model. Effect coding was used for the trip attribute variables. In the model, 500 Halton draws were used for each respondent. This resulted in a stable model.

The results in Table 4 show negative constants for all transport mode alternatives. However, the parameter for regular bike is not significant. This indicates that, when all explanatory variables are evaluated at zero, people are most likely to choose the car or regular bike. The standard deviations are all highly significant, indicating that there is substantial heterogeneity between respondents regarding a base preference for transport mode choice.

With respect to trip distance the results show that for shorter distances (0-6 km) people are less likely to choose the car and most likely to choose a regular bike. For longer trips (22 km) the car is the most preferred mode. As expected, a trip distance of 22 kilometers has a large negative effect on choosing a regular bike. Solar bike and e-bike seem the most preferred modes for medium length trips (14 km).

Regarding trip purpose, the regular bike has a positive coefficient for recreation, whereas solar bike, e-bike and public transport are more likely to be chosen for commuting. Astegiano, Tampère, and Beckx (2015) also found that the e-bike is more often used for commuting than for more occasional trips. As expected and in line with the literature (e.g., Molin & Timmermans, 2010), the weather is found to have a relatively large effect on choosing a regular bike, solar bike or e-bike. In rainy and windy weather, people are more likely to choose public transport or car, whereas in dry weather, different types of bicycles are preferred. Dark has a negative effect on choosing to cycle, with the largest negative parameter for the solar bike. The negative effect of darkness on cycling is in line with findings from other studies (e.g., Molin & Timmermans, 2010). The larger negative coefficient for solar bike is plausible, as the solar bike only charges during daylight.

Table 4: Mixed logit error components model transport mode choice

	Solar bike		E-bike		Regular bike		Public transport	
	B	sig	B	sig	B	sig	B	sig
Constant	-1.552	0.000	-2.096	0.000	-0.422	0.094	-2.196	0.000
Standard deviation	1.733	0.000	2.397	0.000	2.065	0.000	3.021	0.000
Trip distance								
6km	0.314	0.071	0.649	0.000	3.113	0.000	0.447	0.031
14km	0.268		0.267		-0.290		-0.138	
22km	-0.582	0.000	-0.916	0.000	-2.823	0.000	-0.309	0.056
Trip purpose								
Recreation	-0.335	0.004	-0.190	0.114	0.326	0.001	-0.280	0.010
Commuting	0.335		0.190		-0.326		0.280	
Weather								
Windy & rainy	-1.520	0.000	-1.018	0.000	-1.815	0.000	0.234	0.166
Little wind & rain	0.310		0.056		0.403		-0.165	
Little wind & dry	1.210	0.000	0.962	0.000	1.412	0.000	-0.069	0.765
Daylight								
Daylight	0.828	0.000	0.112	0.390	0.362	0.002	-0.170	0.194
Dark	-0.828		-0.112		-0.362		0.170	
Quality bike lanes								
Good	0.337	0.062	0.306	0.070	0.212	0.226	-0.093	0.574
Moderate	0.411		0.089		0.400		-0.247	
Bad	-0.748	0.000	-0.395	0.009	-0.612	0.000	0.340	0.036
Quality public transport								
Good	0.021	0.903	0.223	0.223	0.112	0.448	0.863	0.000
Moderate	0.142		-0.042		-0.025		0.274	
Bad	-0.163	0.340	-0.181	0.289	-0.087	0.591	-1.137	0.000
Crowdedness car								
Calm	-0.391	0.026	-0.335	0.088	-0.330	0.061	-0.374	0.038
Moderate	-0.023		-0.160		-0.131		-0.297	
Congested	0.414	0.004	0.495	0.004	0.461	0.015	0.671	0.000
Crowdedness Public Transport								
Calm	-0.026	0.878	0.169	0.293	0.077	0.663	0.214	0.162
Moderate	0.046		-0.012		-0.023		0.272	
Crowded	-0.020	0.910	-0.157	0.375	-0.054	0.765	-0.486	0.011
Bike parking								
Unsecured free	-0.309	0.066	-0.064	0.741	-0.045	0.790	0.119	0.491
Secured free	0.239		0.012		0.088		-0.145	
Secured parking €1	0.070	0.672	0.052	0.767	-0.043	0.779	0.026	0.873
Car parking								
Free	-0.722	0.000	-0.489	0.005	-0.706	0.000	-0.841	0.000
€ 3.75	0.083		-0.153		0.006		-0.165	
€ 7.50	0.639	0.000	0.642	0.000	0.700	0.000	1.006	0.000

Table 4: Mixed logit error components model transport mode choice (cont.)

Sigma1 (PT, car)	1.828	0.000
Sigma2 (all 3 bikes)	0.326	0.460
Sigma3 (e-bike, solar)	1.078	0.001
N=2711 choice situations among 308 respondents		
Log likelihood function		-2730.161
Restricted log likelihood		-4363.186
McFadden R^2		0.374

When the quality of bicycle lanes is better, people are more likely to choose a bike (regular bike, e-bike or solar bike) over the public transport alternative. This is in line with previous findings cycling (e.g., Hoehner et al., 2005; Parkin et al., 2008; Buehler & Pucher, 2011; Santos et al, 2013; Piatowski & Marshall, 2015; Braun et al., 2016). The larger coefficients for e-bike and solar bike indicate that especially for these types of bikes good quality bike lanes are important while they are a little less important for regular bikes. Bike parking only affects the likelihood of choosing a solar bike. When bike parking is unsecured, people are less likely to choose the solar bike. Our results indicate that quality and crowdedness of public transport only affects the choice of public transport relative to car. It has apparently no effect on choosing the different types of bicycles.

Finally, car parking and crowdedness both strongly affect transport mode choice. When the roads are calm, the car is preferred over all other modes, while public transport and cycling are preferred when car traffic is congested. Regarding parking costs our results indicate that free parking increases the likelihood of choosing the car, while a parking fee of €7.50 has a positive effect on choosing public transport or one of the different types of bicycles. This finding is in line with the literature (e.g., Hess, 2001; Rietveld & Daniel, 2004; Hamre & Buehler, 2014).

The estimates for the error components show that there is a significant correlation between the utility of e-bike and solar bike. The same goes for the utility between the two motorized transport modes. The error component for the nest with all three types of bikes is not significant.

4.2 Results latent class MNL model

The second model is a latent class MNL model on transport mode choice. This model groups the respondents into segments with separate parameters for the alternative specific constants. The aim of this analysis is to group respondents according to their base preferences for different transport modes as this reflects their attitude toward cycling. Therefore, only the constants are entered in the model and not the trip characteristics. The model accounts for the panel data structure of the data. Models with up to five latent classes were estimated. Table 5 shows the number of segments, the number of parameters, the rho-squares, AIC and BIC for each model. The statistics show that the rho-square keeps increasing with and increasing number of classes and the AIC and BIC keep decreasing. However, the changes become smaller with an increasing number of classes. In this study a three-class model was estimated to avoid overfitting. Moreover, in a model with three latent classes a segment with a clear preference for the solar bike can be identified, which provides relevant information for this research.

Table 5: Statistics for latent class models

Nr of classes	Parameters	Log likelihood function (LLB)	Restricted log likelihood (LL0)	p^2=1-LLB/LL0	AIC	BIC
1	4	-4111.774	-4363.186	0.0576	3.03635	3.04506
2	9	-3941.066	-4363.186	0.0967	2.91410	2.93371
3	14	-3812.584	-4363.186	0.1262	2.82301	2.85350
4	19	-3728.364	-4363.186	0.1455	2.76456	2.80595
5	24	-3646.671	-4363.186	0.1642	2.70798	2.76026

Table 6 shows the results of the latent class model with 3 classes, as well as the conventional MNL model. The parameters for the conventional model show the average likelihood for each transport mode. It shows that bike is exactly as likely as car to be chosen. The negative parameters for solar bike, e-bike and public transport indicate that these modes are chosen less often.

The latent segment is not observed. For each respondent, individual parameters were estimated for the travel mode alternatives and latent class probabilities. Respondents were classified into the three segments based on these individual parameters. The latent class specific probabilities are a set of fixed constants, which sum to 1. No membership function was used.

Table 6: Latent class MNL model transport mode choice

	Conventional MNL model		Latent class model					
			Class 1: Solar bike preference		Class 2: car preference		Class 3: Bike and public transport preference	
	B	sig	B	sig	B	sig	B	sig
Solar bike	-0.670	0.000	0.314	0.001	-3.829	0.000	-1.416	0.000
E-bike	-1.042	0.000	-1.634	0.000	-0.818	0.000	-.0902	0.000
Bike	0.000	1.000	-0.131	0.251	-0.730	0.000	1.033	0.000
Public Transport	-0.863	0.000	-1.214	0.000	-2.931	0.000	0.580	0.000
Class probability			0.382	0.000	0.304	0.000	0.314	0.000

4.3 Bivariate relationships between latent class membership and personal characteristics, vehicle ownership and perceptions

Relationships between latent class membership and personal and mobility characteristics were tested using a series of bivariate analyses: cross-tabulations with chi-square tests and analyses of variance. Note that these results are not controlled for correlations among the variables. The results in Table 6 show significant differences between the latent classes and several personal characteristics. As can be seen, more than half of the respondents in the segment with a preference for the solar bike are women, whereas only 30% of the car lovers are female. Regarding age, the results indicate that the segment with a preference for the solar bike are older than average, and the segment that prefers regular bike and public transport has a lower average age. This seems in line with expectations that solar bikes are more attractive for older people, as are e-bikes (Braun et al., 2016; Wolf & Seebauer, 2014).

The bike and public transport segment contains relatively many non-Dutch, whereas the solar bike segment is mainly Dutch. Regarding household composition, the result show that families with children are more likely to have a car preference, while couples are more likely to prefer bike and public transport.

No significant difference is found between the segments with respect to average commute distance, income and education. With respect to occupation the results in Table 7 show that the segment with a preference for solar bike contains a larger share of unemployed or retired people. The segment with a preference for bike and public transport contains a larger than average share of students. This might be related to the fact that students in the Netherlands get a free public transport pass with free travel during off-peak hours and discounts during peak hours.

The results show that 42% of car lovers own one car and another 42% own two cars, while 40% of the respondents in the bike and public transport segment do not own a car. E-bike ownership is also lower for the bike and public transport segment. On the other hand, public transport pass ownership is much higher than average among the bike and public transport segment and lower among the car lovers.

Finally, regarding the perceptions, the results in Table 7 show that the segment who prefers the solar bike is more interested in technological innovation and more environmentally conscious. This seems in line with findings of Wolf and Seebauer (2016) who found that e-bike users have a more positive attitude toward innovation and the environment. This solar bike preferring segment is also most positive about e-bikes and solar bikes, and they have the highest purchase intention.

Table 7: Bivariate relationships between segments and personal and mobility characteristics

	1 Solar bike	2 Car	3 Bike and PT	Total	X^2 or F (sig.)
Gender					
Male	48.7%	70.0%	57.4%	57.8%	9.454 (0.009)
Female	51.3%	30.0%	42.6%	42.2%	
Age					
Years	44.29	41.19	35.71	40.57	10.342 (0.000)
Nationality					
Dutch	92.3%	87.8%	81.2%	87.3%	6.083 (0.048)
Other	7.7%	12.2%	18.8%	12.7%	
Household composition					
Single	17.9%	27.8%	24.8%	23.1%	13.508 (0.009)
Couple	40.2%	27.8%	49.5%	39.6%	
Family	41.9%	44.4%	25.7%	37.3%	
Commute distance					
Kilometers	23.38	20.13	34.52	26.08	2.168 (0.116)
Income					
€ 0 - € 1900	30.8%	23.3%	28.7%	27.9%	6.661 (0.353)
€ 1901 - € 2700	19.7%	15.6%	25.7%	20.5%	
€ 2701 - € 3500	21.4%	25.6%	15.8%	20.8%	
> € 3500	28.2%	35.6%	29.7%	29.7%	
Education					
Secondary	15.4%	10.0%	5.9%	10.7%	5.122 (0.077)
Higher	84.6%	90.0%	94.1%	89.3%	
Occupation					
Unemployed/retired	11.1%	3.3%	4.0%	6.5%	31.474 (0.000)
Student	13.7%	13.3%	19.8%	15.6%	
Working part time	32.5%	14.4%	9.9%	19.8%	
Working fulltime	42.7%	68.9%	66.3%	58.1%	
Cars in household					
0	16.2%	15.6%	40.6%	24.0%	29.814 (0.000)
1	51.3%	42.2%	43.6%	46.1%	
2 or more	32.5%	42.2%	15.8%	29.9%	
E-bike ownership					
Yes	13.7%	15.6%	4.0%	11.0%	7.851 (0.000)
No	86.3%	84.4%	96.0%	89.0%	
PT discount card					
Yes	50.4%	41.1%	69.3%	53.9%	16.140 (0.000)
No	49.6%	58.9%	30.7%	46.1%	
Perception innovation					
1-7	3.22	2.84	2.88	3.00	4.628 (0.011)
Perception environmentally conscious					
1-7	3.78	3.53	3.73	3.69	5.352 (0.005)

Table 7: Bivariate relationships between segments and personal and mobility characteristics (cont.)

Perception e-bike					
1-7	3.28	3.13	2.92	3.12	10.356 (0.000)
Perception s-bike					
1-7	3.48	3.28	3.17	3.32	12.073 (0.000)
Likely to buy S-bike					
1-7	3.58	2.30	2.18	2.75	33.672 (0.000)

5 Conclusion

The new development of the solar bike has raised the question of which factors influence the stated use of the solar bike and to what extent can it be an interesting alternative for motorized transport modes. This study has presented the results of a stated choice experiment on mode choice among 308 respondents. Descriptive statistics of the mode choice experiment showed that in general across the presented choice situations both car and regular bike are preferred, as they each accounted for 30% of the choices. The solar bike was chosen in 16% of the 2711 choice tasks.

The results of the mixed logit error components model indicated that when the weather is good the likelihood of choosing the solar bike, as well as regular bike an e-bike is higher than when it is rainy or windy. Daylight also has a positive effect on choosing all types of bicycles, with the largest effect on the solar bike, as the solar bike only charges when there is sunlight. Good quality bike lanes, secured bike parking, paid car parking and car congestion all have a positive effect on choosing the solar bike. The solar bike is more often chosen for commuting than for recreation. The utility of the solar bike is highest for medium trip distances (14 kilometer).

In a latent class MNL model the respondents were clustered in three segments. The first segment, with a preference for solar bike, consists of 38% of the respondents. The second segment consists of 30% of the respondents and has a clear preference for car. The third segment has a preference for regular bike and public transport and contained 31% of the respondents. Bivariate analyses showed that the segment that prefers the solar bike contains a larger share of females, Dutch and unemployed or retired respondents, and has the highest average age. This segment is also more interested in technological innovation, more environmentally conscious, most positive about e-bikes and solar bikes, and has the highest solar bike purchase intention. The finding that females and retired persons are most interested in new technology is surprising, as it is contradictory to what most other studies on innovations find, namely that the young and males are most interested in technology.

The results of our study suggest that land-use planning and urban design can be used to manage travel demand and behavior. Our results indicate that good quality bike lanes can stimulate cycling with all three types of bicycles, with the highest positive effect on choosing the solar bike. Improving cycling infrastructure (e.g., separate bike paths, smooth pavement, few crossings or stops, no hindrances) should therefore be an aim for cities who want to increase cycling rates. In addition, paid car parking can also be an effective means as it motivates people to use alternative modes of transport.

The utility of the solar bike is higher for commute trips than for recreational trips. Employers who want to increase cycling rates of their employees, would be advised to arrange secured bike parking facilities. For charging the solar bike it is important that daylight can reach the bike in the bike parking.

Although our study provides interesting results regarding stated use of the solar bike, it has some limitations. Due to our recruitment process at the universities, the sample contains mainly highly educated people. It is therefore not representative of the Dutch population.

Moreover, in our stated choice experiment on mode choice respondents could choose among a regular bike, and e-bike and a solar bike, which implies that all three bike alternatives are available to a respondent. It may not be very realistic to assume that all respondents have all three types of bicycles available. In addition, the option of a solar bike may be difficult to imagine for respondent, as it is a product that most respondents have not seen in real-life. The actual use could change people's perceptions of a solar bike. In future research we plan to have respondents testing the solar bike and to collect information on their experiences and perceptions.

Future research of (stated) solar bike acceptance and use in different countries with other cycling conditions than the Netherlands (e.g., slopes, different weather conditions) would also interesting to increase our understanding of the possible uptake of this new type of bicycle.

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